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LA-UR-87-1484

CONF-871045-2

LA-UR--87-1484

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TITLE THE LOS ALAMOS CRITICAL EXPERIMENTS FACILITY PROGRAM

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SUBMITTED TO International Seminar on Nuclear Criticality Safety
Tokyo Yubinchokin kaikan Hotel
Tokyo, Japan
October 19-23, 1987

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FORM NO 836 R4
ST NO 2629 5/81

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THE LOS ALAMOS CRITICAL EXPERIMENTS FACILITY PROGRAM

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ABSTRACT

Critical assemblies of precisely known materials and reproducible and easily calculated geometries have been constructed at the Los Alamos National Laboratory since the 1940s. Initially, these assemblies were built to provide information necessary for the nuclear weapons development effort. Subsequently, intensive studies of the assemblies themselves were undertaken to provide a better understanding of the physics of the fission process and other nuclear reactions in the nuclear materials from which these machines were constructed and in other materials irradiated in these assemblies. Some of these assemblies (notably Jezebel, Flattop, Big Ten, and Godiva) have been used as benchmark assemblies to compare the results of experimental measurements and computations of certain nuclear reaction parameters. These comparisons are used to validate both the input nuclear data and the computational methods. In addition to these normally fueled benchmark assemblies, other assembly machines are fueled periodically to provide specific and detailed results for parameter sensitivity studies for a large number of applications. Some of these machines and their applications are described.

INTRODUCTION

The Los Alamos Critical Experiments Facility (LACEF) was constructed and continues to operate as a facility suitable for the safe handling of fissile materials in diverse forms and configurations in essentially any quantity sufficient for the experimental purposes. And these purposes have been numerous. A History of Critical Experiments at Pajarito Site[1] and a companion document, Thirty-Five Years at Pajarito Canyon Site,[2] recount many of these purposes. In 1946, the Pajarito Canyon site was chosen for the operation of critical assemblies because its isolation from the rest of the Laboratory would provide the necessary protection of other Laboratory sites should a criticality accident occur. This use of isolation for protection was maintained in the design of the LACEF itself. The facility features three separate, lightly shielded laboratories known as kivas that are located one-quarter mile from the main laboratory building. Each kiva contains several critical assembly machines that are operated remotely from control rooms in the main laboratory building. Special nuclear materials, and even entire machines, may be moved from one kiva to another. Fissile materials are routinely handled (remotely when near critical) in a multitude of configurations. All physical forms - solid, liquid, gas - have been studied. The general purpose assembly machines have been run at or near delayed critical with loadings ranging from a few hundred grams to hundreds of kilograms of fissile material. We also pioneered the study of superprompt critical excursions in fast metal assemblies.

The objective of the early work at the LACEF was to provide criticality safety guidance in handling, transporting, and storing nuclear weapon components. In addition to such safety tests were experiments designed to validate the calculations of the neutronic properties of weapons. These types of experiments have continued and expanded to validate computational methods and input data sets for various configurations of fissile, reflecting and moderating materials considered for both military and civilian applications. A considerable effort was expended in the 60s and 70s in running operational checkouts of the prototype nuclear rocket engines.

The measurement data used to validate calculations include the neutron and gamma-ray energy spectra and the cross sections of various materials within the assembly, integrated over the neutron energy spectrum. These data are usually obtained as:

- spectral indices, the ratios of fission rates of isotopes with significantly different integral response, such as $\sigma_f(^{238}U)/\sigma_f(^{235}U)$, $\sigma_f(^{239}Pu)/\sigma_f(^{235}U)$, and $\sigma_f(^{237}Np)/\sigma_f(^{235}U)$;
- the Rossi-α at and above delayed critical,
- the measurement of periods resulting from small reactivity changes above delayed critical,
- the measurement of neutron population dieaway for large negative reactivity changes from delayed critical;
- the central reactivity coefficients of a wide variety of materials and the spatial variation of the reactivity coefficients of these materials, and
- the differential leakage radiation spectra.

Since the last International Seminar on Nuclear Criticality Safety in Dijon, we have been engaged in an expanded program of experimentation and computation in support of several offices in the USDOE.

Some of the more recent activities have included the construction of an exact replica of the Little Boy weapon, recommissioning of the fast burst assembly SKUA, the construction of a new core (called the Swiss Cheese Assembly) for our general purpose vertical lift machines, the remeasurement of the thickness of beryllium reflector for a critical configuration with a plutonium sphere, the measurement of the neutronic properties of isolating and reflecting materials for uranyl nitrate-containing slab tanks and annular tanks, the effects of soluble poisons on reactivity for uranyl nitrate

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED solution-processing vessels, both reflected and bare, the reevaluation of source jerk and Rossi-α measurements for reactivity determinations, the construction of the prototype of a compact nuclear power source, the remeasurement of delayed neutron parameters, and the continued instruction of Special Nuclear Materials (SNM) workers in criticality safety. Each of these activities is described in some detail in the following.

ASSEMBLY DESCRIPTIONS

1. Benchmark Fast Neutron Critical Assemblies

Of the benchmark fast-neutron critical assemblies Jezebel, Flattop, Big Ten and Godiva, Jezebel no longer exists. In addition to those listed, another fast-burst assembly, SKUA, has been built but not yet completely characterized.

a. Godiva IV is the latest in a line of unreflected enriched-uranium metal critical assemblies. The original spherical "Lady Godiva" was constructed to determine the critical mass and neutronic behavior of an unreflected ^{235}U sphere. In the later Godiva machines (such as Godiva IV) cylindrical geometry was selected for structural strength and reduced thermal shock when these machines were operated in the fast-burst mode (operation beyond critical on prompt neutrons alone). These bursts have been used to demonstrate nuclear pumping of lasers, to simulate fast reactor accident transients in fuel pins; to evaluate responses of fluors used in electrooptical imaging systems; to image using coded apertures and neutrons and gamma rays to produce short-lived isotopes, to study radiation response to instrumentation, and to produce plant life genetic mutations.

b. Jezebel was constructed to determine the critical mass and neutronic behavior of an unreflected sphere of delta-phase plutonium metal (4.5% ^{240}Pu). Its support and control structure were designed to minimize extraneous reflection. Measurements with Jezebel supplied the same confirmatory information for plutonium that was obtained for uranium with Lady Godiva. The internal neutron spectrum and the neutron lifetime and relative reaction cross sections for various isotopes in the Jezebel neutron spectrum were measured.

The Jezebel assembly has also been used to assemble unreflected metal spheres of ^{233}U and of plutonium with a significant ^{240}Pu enrichment (20%). Detailed neutronics measurements were made with each sphere. Comparing the measurement results from the three spheres provides a more precise understanding of the neutronic behavior of each of them separately.

c. Flattop is an assembly whose characteristics have been firmly established over many years of measurements and calculations. The assembly consists of a spherical core of either uranium (93.2% ^{235}U or 98.1% ^{233}U) or plutonium (5% ^{240}Pu) metal, and a thick, spherical natural uranium reflector. Because the reflected cores are different in size, adapter shells of natural uranium allow adjustment of the core cavity size. Flattop assembly spectra are characteristically hard at the center and degraded in the reflector. This position-varying neutron spectrum is particularly useful for neutron activation studies and reactivity coefficient measurements. Intercomparisons with the results of the same measurements in the other benchmark assemblies provide integral reaction rate information over a very broad range of neutron energies. Jezebel and Godiva have hard spectra, Big Ten has an intermediate spectrum, and Flattop has a spectrum that is position variable from hard to intermediate. The details of measurement methods and the complete physical description of the Jezebel and Flattop assemblies and Godiva II are found in the December 1960 issue of Nuclear Science and Engineering. Godiva IV is described in Reference 3.

d. Big Ten is a normally-fueled version of a horizontal split table critical assembly made of uranium metal. The core is composed of a central section of homogeneous 10% enriched uranium enclosed in a region of alternating 93% enriched and natural uranium plates simulating an overall 10% enrichment. The outer reflector is depleted uranium. The composition of Big Ten is such that the central neutron spectrum is comparable to that of the Liquid Metal Fast Breeder Reactor (LMFBR) so that verification of cross-section sets in Big Ten would validate them for LMFBR calculations. However, the greatest utility of the machine is in comparisons of the measured and calculated reaction rates in samples that can be introduced into the central region of the core. Because this machine has a highly reproducible geometry and – like Flattop, Godiva IV, and Jezebel – has been very well characterized, it too is considered a bench-mark assembly. The reaction rate comparisons for Big Ten, then complement the same comparison for Jezebel, Godiva, and Flattop, and together these form an impressive integral test of cross-section sets and computational methods. Reference 4 is a complete description of the Big Ten assembly.

e. SKUA is the sixth fast burst assembly (the others being Lady Godiva, Godivas II, III, IV, and Moly G-WSFBR) to be developed at Los Alamos. The fuel is enriched uranium, U(93), metal, alloyed with 1.5% molybdenum in the form of a hollow right-circular cylinder made up of a stack of 12 annular rings. This stack is 30.5 cm high with nominal 24.1 cm and 31.8 cm inside and outside diameters, and weighs 188 kg. Reactivity control is achieved with six copper reflector segments, three of which move by hydraulic actuators in the radial direction to provide the independent major shutdown or SCRAM mechanisms. The other three are rotating control drums. The central fluence in SKUA is a factor of 5 larger than that of Godiva IV. SKUA is described in detail in Reference 5.

2. General Purpose Assembly Machines

a. The Honeycomb Critical Assembly is a universal horizontal split table machine containing a 1.83-m (6 ft)-cubical matrix of 76-mm (3 in.)-square aluminum tubes. It is designed to serve as a flexible system for initial mockup studies for basic critical parameter investigations. Fuel inventory consists of various fissile species such as 330 kg of 0.05-mm-thick U(93%) foils with widths and lengths appropriate to the aluminum matrix tubes. Controls and safety rods utilize sections of the core or reflector materials for their function and major disassembly is provided by the movable section of the table. Honeycomb was recently stacked with a UO_2-MO (core), Be (reflector) mockup of a space power reactor.

b. The Comet machine is a general purpose vertical assembly machine that has been used for many critical determinations and nuclear safety studies. It is basically a support stand with means for bringing two parts of a configuration together. A hydraulic ram brings a lower table up to position near the top platform holding part of the SNM. Secondary vernier motion on top of this table bringing the remainder of the core together is accomplished by means of a screw-driven platform powered by a stepping motor, with accurate position readout in the control room. Comet provides a flexible facility for conducting a variety of experiments on short notice. Comet was employed in a series of measurements to evaluate ^{242}Pu cross sections and is used for various stackings of interest to criticality safety and other code validation experiments.

c. Venus and Mars are heavy duty vertical lift assembly machines. They consist of a rugged stand and a hydraulic cylinder recessed into the floor. A cart and track arrangement permits components to be positioned over the hydraulic piston or removed to a more accessible area as desired. These machines were built for the Rover (nuclear rocket) program and were used continually during that program for a wide range of mockup studies. Mars was used for a study of gaseous core reactor concepts and is being used for the Compact Nuclear Power Source reactor critical experiments. Venus is being used for the uranyl nitrate storage tank critical experiments.

d. Sheba is a bare assembly fueled with a solution of approximately 5% enriched uranyl fluoride initially stored in two horizontal 25.4-cm-diameter by 1.5-mm-long "safe" stainless steel tanks. The solution is transferred to the reactor cavity (a 56-cm-diameter by 1.3-m-high stainless steel tank with 0.64-cm-thick walls) by evacuating the cavity while applying helium pressure to the storage tanks. A completely clean geometry is provided in this simple cylindrical system, because reactivity control is affected by varying the solution level. A "safety rod" may be inserted in a central thimble to provide fast shutdown. The original purpose was to provide a radiation source similar to those in proposed centrifuge processing plants to set a standard for calculations and to evaluate criticality accident alarm detectors and personnel dosimetry.

EXPERIMENTAL PROGRAM

1. Little Boy Replica

The non-nuclear components of a Hiroshima-type bomb that had been retired from stockpile and stored at Los Alamos were used in this set of measurements. Those components were mounted on the Comet Assembly machine and the fissile material inserted via the hydraulic lift platen and lead screws of the assembly. Three basic types of experiments were done: critical separation distance measurements to establish the upper limit for the yield of the device dropped on Hiroshima; leakage neutron and gamma ray energy spectra measurements to compare with calculations, and phenomenological experiments involving the measurement of radiation fields and the exposure of roof tiles, power line insulators and whole blood. For the critical separation measurements, fissile parts were fabricated using the original Hiroshima bomb drawings and specification sheets. For the spectra and phenomenological measurements, an amount of fissile material just sufficient to allow sustained operation at delayed critical was used. Measurements were made both with the assembly inside the assembly building and on a stand outside the building. The replica measurements are of immense value in resolving uncertainties in the calculations of the output of the Hiroshima device.

2. Beryllium Reflected Plutonium Spheres

We are repeating a 1958 Lawrence Livermore National Laboratory (LLNL) experiment on the thickness of beryllium reflector required to make a sphere of plutonium critical. This experiment is being conducted to attempt to resolve a long-standing discrepancy between the earlier measurement results and all subsequent calculations of those results. We are reducing the mass of the sphere and increasing the thickness of beryllium in this series of measurements with the objective of determining the minimum mass of plutonium for an infinitely thick beryllium reflector. We began the series with a stainless steel clad 4.5 kg sphere of α-phase plutonium and beryllium reflector hemishells larger than the thickness calculated to take the system critical. Using the Comet Assembly Machine, we measured the critical separation distances between the hemishells as material was removed from the outside radius of the hemishells. The final machining to a beryllium thickness of 8.395 cm produced a closed configuration that was slightly supercritical at room temperature but subcritical at an elevated temperature resulting from internal intrinsic heating of the plutonium. Our current estimate for the 20 °C critical beryllium reflector thickness for the 4.5-kg plutonium sphere is 8.33 cm, compared with the 1958 LLNL result of 9.40 cm and the present Monte Carlo code calculated value of 7.26 cm. The search for the reasons for the remaining discrepancy continues.

3. Slab and Annular Storage Tanks

Westinghouse Idaho Nuclear Corporation (WINCO) requested that we make measurements, under the auspices of the USDOE Office of Nuclear Materials Production, on proposed storage arrays for highly enriched uranyl nitrate solutions so that comparisons between computed keff and the measured or extrapolated delayed critical condition could be made. Two types of individual storage tanks were envisioned: an annular tank and a slab tank. In both cases, the effects of isolating, moderating and reflecting materials were determined.

The annular tank had an outer diameter of 76 cm and an inner diameter of 57 cm and a height of 179 cm (all dimensions approximate). The uranyl nitrate solution had a concentration of 0.2092 gU/gSolution with a density of 1.4228 gSolution/cm^3 and an enrichment of 93%. The bottom of the tank was 0.95 cm thick and the radial and top walls were 0.32 cm thick (all 304 L stainless steel).

The three cylindrical "slab" tanks used in these experiments are ~3.5 in. in diameter and the inner axial heights are 4.25 cm, 9.04 cm, and 10.74 cm. Each tank was filled with 93.1 wt.% ^{235}U uranyl-nitrate solution containing 405.2 g/l uranium with an overall density of 1.558 g/l.

4. Dissolver Tank Poison Evaluation Experiment

The fluorinal and storage (FAST) dissolver built by WINCO uses a soluble boron compound for criticality prevention. To validate the criticality code used by Westinghouse, Los Alamos National Laboratory designed and performed a series of experiments intended to simulate the important neutronic characteristics of the FAST dissolver. For that purpose, a nickel-reflected solution assembly fueled with highly enriched uranyl-nitrate solution containing relatively high concentrations of boron was built. An outer reflector region was designed to allow either no reflector (air) or a water reflector, whereas the inner reflector region was designed to allow no reflector (air) or a 12.7-mm-thick (0.5-in.) nickel reflector. Hence, four reflector configurations were possible: (1) outer reflector of air and inner reflector of air, (2) outer reflector of air and inner reflector of nickel, (3) outer reflector of water and inner reflector of air, and (4) outer reflector of water and inner reflector of nickel. The reactor was fueled with uranyl-nitrate containing 305 ± 1 g/l 93.15% enriched uranium. Boric acid (enriched in ^{10}B to 52.3 atm.%) was dissolved into the uranyl-nitrate solution in a step-wise fashion. The critical height for the four different reflector configurations was measured as a function of boron concentration. A total of 29 delayed critical conditions were achieved with seven natural boron concentrations ranging from 0 to 7.46 grams per liter and the various reflector combinations.

5. Characterization of Reactivity Measuring Methods

Recent interest in measuring $k_{eff} << 1$ has spurred the development of several new techniques and revived interest resurrected old, but seldom used, techniques.

There is a general mistrust of any measurement of k_{eff} obtained in subcritical systems for which $k_{eff} << 1$. This mistrust is justifiable, as k_{eff} departs farther from 1.0, spatial variations in the neutron flux can produce biases in the measurement depending on the exact location of the detector(s). The magnitude of these biases as a function of k_{eff} has not yet been determined in any sysematic fashion, hence, it is unknown if these techniques can be adapted successfully to measure k_{eff} in highly subcritical systems.

A special assembly was built to provide an assortment of holes in which sources or detectors can be placed. The assembly consists of thin uranium foils sandwiched between 1-in.-thick acrylic resin plates. The plates are stacked to obtain a k_{eff} that ranges from 0.1 to 1.0. Numerous holes drilled into the acrylic plates will be plugged with acrylic rods when they are not occupied by either a source or a detector. Thus, comes the name "Swiss Cheese Assembly" for this new apparatus.

Eight detectors can monitor each experiment. Among the class of experiments we are conducting is the "source jerk" using the inverse kinetics technique. Another is an electronically sophisticated "Rossi-α." We are expecting that our versatile "Swiss Cheese Assembly" will allow us to make significant improvements in our ability to determine k_{eff} from measurement data. Using a technique developed at Los Alamos, the signals will be analyzed both individually and as an appropriately averaged "net" signal to determine the variation in k_{eff} as well as the best estimate of k_{eff}. The detector and source locations will also include positions external to the assembly.

6. The Compact Nuclear Power Source Reactor

We have constructed a prototype of a graphite-moderated, low enriched uranium (20%) fueled power source that has been designed for long life stable generation of approximately 3 [illegible] watts electric power using an organic Rankine cycle operated from heat pipes carrying the primary thermal heat from the core. We are making approach to critical measurements, reactivity worth determinations for all fuel and structural materials and control elements, temperature coefficients of reactivity, and fission flux profile measurements.

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